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Carbon Dioxide Levels in Railcars and Their Effect on Lettuce

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Carbon Dioxide Levels in Railcars and Their Effect on Lettuce

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SUMMARY

Carbon dioxide (CO_2) and oxygen (O_2) concentrations were determined during transit in 10 test cars of lettuce shipped from Salinas, Calif., to eastern markets. Market quality of test packages of lettuce from these cars was evaluated at destination.

Eight of the cars were conventional mechanically refrigerated cars in which no effort was made to modify the atmospheres. Any modification that did occur was due to the respiration of the lettuce and the tightness of the cars. Atmospheres in two of the cars were modified at shipping point by the Transfresh Corporation to provide low O_2 levels and high carbon monoxide (CO) levels.

Average CO_2 levels during transit ranged from a low of 0.4 percent in one conventional car to 3.9 percent in another. Three of the eight conventional cars had average CO_2 levels of 2.7, 3.6, and 3.9 percent, respectively. There was a highly significant positive correlation between the average percentage of CO_2 in conventional cars during transit and the occurrence of brown stain in lettuce from those cars.

Carbon dioxide averaged 1.5 percent in each Transfresh-treated car. Incidence of brown stain was significantly higher, at a given level of CO_2, in the Transfresh cars than in the conventional cars.

Calmar, the principal lettuce cultivar grown in the Salinas Valley, developed more brown stain than R-200. However, since the two cultivars were not from the same field, and differed in maturity, the difference in brown stain could have been due to environmental rather than genetic factors.

In the conventional cars, the CO_2 level during transit did not affect russet spotting, decay, pink rib, tipburn, butt discoloration, or general external appearance of the heads.

In the Transfresh cars, russet spotting was reduced and brown stain was increased, but the effects of the controlled atmosphere on the other quality factors were not consistent in the two cars.

BACKGROUND

Shipping and laboratory tests by the U.S. Department of Agriculture have linked higher than normal levels of carbon dioxide (CO_2) with brown stain, a recently described disorder of lettuce (fig. 1.).[1]

Today mechanically refrigerated railcars are being constructed tighter than previously to improve the efficiency of the refrigeration and to facilitate the deliberate modification of the car atmosphere for those shippers desiring this service. Commodities with high respiration rates, such as lettuce, cause a modification of the atmosphere in these tightly constructed cars. The carbon dioxide levels tend to build up and oxygen (O_2) levels, to be reduced. Because of the relationship observed between CO_2 levels and brown stain, and because of the absence of continuous CO_2 records during transit in the

[1] Stewart, J. K., Ceponis, M. J., and Beraha, L. Modified-atmosphere effects of the market quality of lettuce shipped by rail. U.S. Dept. Agr. Mktg. Res. Rpt. 863, 10 pp., illus. 1970.

Stewart, Joseph K. and Uota, M. carbon dioxide injury and market quality of lettuce held in controlled atmospheres. Jour. Amer. Soc. Hort. Sci. 96(1): 27-31, illus. 1971.

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FIGURE 1.—Brown stain in lettuce: *Left,* Typical lesions, about ¼-inch wide by ½-inch long; *Right,* severe brown stain.

new railcars, a 10-car test shipment of lettuce was made from Salinas, Calif., to the New York marketing area during July and August in 1970.

The cars were accompanied from California as far as Chicago and were met at destination on the east coast by J. K. Stewart (ARS) and J. F. Jones (PFE). Carbon dioxide and O_2 levels in the cars were measured both enroute and at destination, and the market quality of the lettuce was evaluated at destination.

METHODS AND MATERIALS

Railway equipment.—Ten Pacific Fruit Express (PFE) railcars of the 450,000 to 458,000 series were used in the test. Atmospheres in two cars were modified at shipping point, using the Transfresh system to provide low O_2 and high carbon monoxide (CO) levels during transit. Between 200 and 300 pounds of lime were placed in each Transfresh car to remove excess CO_2. Atmospheres in the other eight cars were not modified at shipping point.

The thermostat was set at 34° F. in each of the 10 cars.

Loads.—Each car was loaded with 1,120 to 1,165 vacuum-cooled cartons of lettuce at Salinas on July 28, 1970. All loads were the conventional, solid-through loads in which most cartons were placed lengthwise on bottoms. Each carton contained 24 heads of naked-packed lettuce.

Test packages.—Four test cartons of lettuce were placed in each car in the top layer, near the doorway, to facilitate recovery at destination. Two test packages contained Calmar, the principal cultivar of lettuce grown in the Salinas Valley during the summer months, and two contained R-200, a cultivar grown to a limited extent in the Salinas area. All the test packages of a given cultivar were from the same field.

Routing.—Test car numbers, shippers, receivers, routing, destination, and unloading dates are shown in table 1. All 10 test cars had the same routing as far as Chicago so they could be kept together and atmosphere data could be obtained during transit. Routing of the cars differed beyond Chicago. Although all the cars were scheduled originally for delivery to the east coast, car 9 was diverted to Solon, Ohio.

Seven cars were unloaded at the Hunts Point Market, N.Y., one at Waverly, N.J., and another at Elmsford, N.Y.

Atmosphere evaluation.—The atmosphere in each car was tested by inserting a ¼-inch plas-

TABLE 1.—*Test car numbers, shippers, receivers' data, and routing for cars of lettuce shipped from Salinas, Calif., on July 28, 1970, to indicated destinations*

Shipper and test car No.[1]	Receiver	Routing[2]	Destination	Unloading date
The Garin Co.,				
No. 1[3]	Post & Taback	SP-UP-CNW-PCNY-PCH	Hunts Point, N.Y.	Aug. 4.
Salinas Lettuce Farmers'				
Coop., No. 2	Kleiman & Hochberg	SP-UP-CNW-PCNY-PCH	do	Do.
InterHarvest, Inc.:				
No. 3	Yeckes Eichenbaum Inc.	SP-UP-CNW-PCNY-PCH	do	Do.
No. 4	M. Singer's Sons Corp.	SP-UP-CNW-PCNY-PCH	do	Do.
No. 5	Prevor Mayrsohn Inc.	SP-UP-CNW-PCNY-PCH	do	Do.
No. 6	Yeckes Eichenbaum Inc.	SP-UP-CNW-PCNY-PCH	do	Do.
Bruce Church, Inc.:				
No. 7	Great A&P Tea Co.	SP-UP-CNW-PCP	Waverly, N.J.	Aug. 6.
No. 8	Great A&P Tea Co.	SP-UP-CNW-PCNY	Elmsford, N.Y.	Aug. 5.
No. 9[3]	Kroger Co.	SP-UP-CNW-N&W	Solon, Ohio	Do.
Mutual Vegetable Sales,				
No. 10	D.M. Rothman Co., Inc.	SP-UP-CNW-PCNY	Hunts Point, N.Y.	Aug. 4.

[1] All were 50-foot Pacific Fruit Express cars, mechanically refrigerated, with thermostats set at 34° F.

[2] Railroad abbreviations: SP, Southern Pacific; UP, Union Pacific; CNW, Chicago and Northwestern; PCNY, Penn Central (old New York Central routing); PCH, Penn Central (old New Haven routing); PCP, Penn Central (old Penn Central routing); N&W, Norfolk and Western.

[3] Car atmospheres modified by Transfresh Corp.

tic tube through a water drain in the brake end of the car. From there, the tube was extended into a business car where gas samples could be drawn and analyzed during transit. The tubes were attached underneath the cars and along the air hoses to prevent their pulling apart during transit (fig. 2). Five test cars were in front of the business car and five were behind it.

Air samples were periodically drawn from the test cars with a small electric air pump. All the cars were analyzed for CO_2 and O_2. The Transfresh cars also were analyzed for CO. Oxygen and CO_2 were analyzed with portable volumetric gas analyzers, and carbon monoxide, with an Orsat-type analyzer (fig. 3).

During certain atmosphere sampling, the elevation of the roadbed also was determined, using an altimeter, or the railroad timetables if the exact location was known.

Temperature measurement.—Ryan-recording thermometers were placed in two test packages in each car to record transit temperatures of the test lettuce.

Lettuce temperatures also were measured at shipping point in all test cars, except car 2. Temperatures of lettuce in cars 1, 3, 6, and 7

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FIGURE 2.—Atmosphere sampling tubes were attached to the air hoses of the cars to prevent breakage during transit.

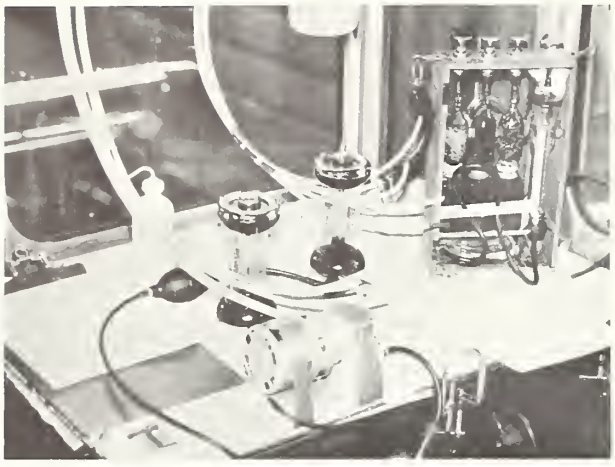

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FIGURE 3.—Pump for drawing air samples, sampling tubes, and gas analyzers used to determine the atmospheres in 10 test cars of lettuce during transit.

were measured only at the doorway as these cars already were loaded by the time the test packages were ready to be placed in them. Temperatures in the other cars were measured at various locations during loading.

Market quality evaluation.—Test packages from each car, except car 9, were recovered as soon as possible after arrival and taken to the U.S. Department of Agriculture's Market Pathology Laboratory at Beele Mead, N.J. Half the lettuce from each test package was evaluated as soon as possible for the arrival examination and the rest was examined after it had been held an additional 4 days at 50° F. in normal air.

The arrival examination of the lettuce from car 9 was made at destination (Solon, Ohio) and the rest was transported to the Department's Pathology Laboratory in Chicago, Ill., where it also was evaluated after being held 4 days at 50° F.

Quality of the lettuce was evaluated by tearing apart each head, leaf by leaf, and determining the incidence and severity of brown stain, russet spotting, pink rib, decay, tipburn, and butt discoloration. The severity of the disorders was rated on a scale in which 1 was none; 2, trace; 3, slight; 4, moderate; and 5, severe. The overall general appearance of the heads before the wrapper leaves were removed also was rated. The scale for this rating was 1, unsalable; 2, poor; 3, fair; 4, good; and 5, excellent. Butt discoloration was not considered when making the general appearance ratings.

Statistical analyses.—Data were evaluated by split-plot analysis of variance, using cars as replications, cultivars as whole plots, and examinations as split plots. Since the cars differed in CO_2 level, a regression of each quality factor on CO_2 also was calculated for the conventional cars. The data for all 10 cars were fitted to the regression line based on the eight conventional cars by the formula given by Acton.[2]

The sums of deviations from regression squared (SSD) so calculated were then subdivided into those attributed to Transfresh cars and those to conventional cars. The mean square deviations of the conventional cars were used as an error term to test the significance of the regression mean square and the mean square deviations due to the Transfresh cars. For three quality factors (appearance, decay, and tipburn), the total SSD from regression exceeded the SSD from the mean and negative values for the regression on CO_2 resulted.

This procedure tested whether the quality factors from Transfresh cars were different from the expected values using only the conventional cars.

Correlation coefficients were determined in the conventional way.

RESULTS

Atmosphere Composition

Conventional cars.—Average CO_2 concentrations in the eight conventional cars varied from 0.4 (car 8) to 3.9 percent (car 5) during transit (table 2). The minimum, maximum, and average CO_2 concentrations in the eight cars are shown in figure 4. Average CO_2 increased to a peak of 2 percent about 28 hours after

[2] ACTON, FORMAN S. ANALYSIS OF STRAIGHT-LINE DATA. P. 18. John Wiley & Sons, N.Y. 1959.

TABLE 2.—*Carbon dioxide (CO_2) concentrations, lettuce temperatures, and weight loss from lettuce shipped in test cars from Salinas, Calif., July 28, 1970*

Test car No.	CO_2 concentration in car		Lettuce temperatures		Weight loss from test packages in transit
	Average in transit	At destination	At loading	Average in transit	
	Percent	Percent	°F.	°F.	Percent
1 [1]	1.5	1.4	40	37	0.8
2	3.6	5.8	—	35	.7
3	1.1	1.4	36	35	.5
4	1.0	1.8	36	35	.5
5	3.9	6.6	37	36	.7
6	1.3	2.4	35	34	.8
7	.5	.5	34	36	.7
8	.4	.5	38	38	—
9 [1]	1.5	2.3	35	36	—
10	2.7	4.3	36	36	1.1

[1] Car atmospheres modified by Transfresh Corp.

leaving Salinas, then decreased about ½ percent, and remained at about 1½ percent until the cars reached Chicago. Atmospheres were not taken between Chicago and the east coast, but at destination the average CO_2 had increased to about 3 percent.

Carbon dioxide levels at destination were high in three conventional cars: 5.8 percent in car 2; 6.6 percent, car 5; and 4.3 percent, car 10. Cars 7 and 8 each had relatively low CO_2 levels of 0.5 percent at destination, while the other cars were intermediate (table 2).

Elevation during transit did not appear to have a distinct effect on the CO_2 level in the cars (fig. 4). However, these data do not permit separating the effect of time in transit and elevation on the CO_2 level.

There was a highly significant positive correlation between the percent CO_2 at destination and the average percent CO_2 during transit among the eight conventional cars (fig. 5). The higher the CO_2 at destination, the higher was the average percent CO_2 during transit.

Also a highly significant, positive correlation existed between the percent CO_2 in the eight conventional cars at Chicago and the average

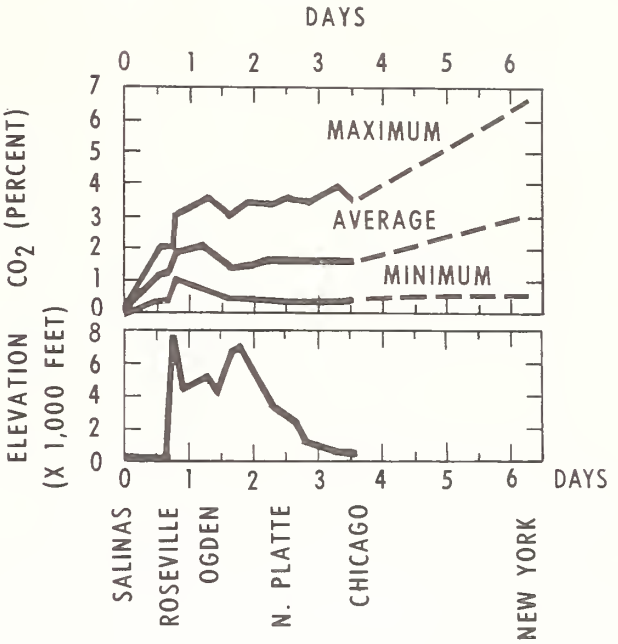

FIGURE 4.—Average, maximum, and minimum carbon dioxide (CO_2) concentrations in eight conventional railcars of lettuce shipped from Salinas, Calif., July 28, 1970, to east coast markets. Elevation of roadbed at certain points also shown.

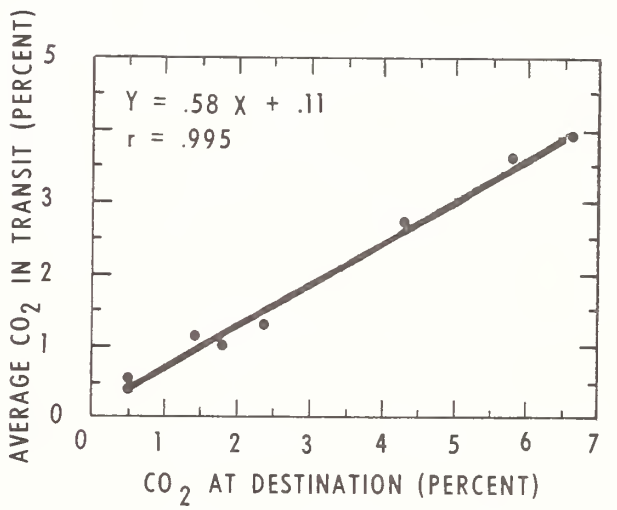

FIGURE 5.—Relationship between the carbon dioxide (CO_2) concentration at destination in eight conventional cars of lettuce and the average CO_2 concentration in these cars during transcontinental shipment; r is significant at the 1-percent probability level.

percent CO_2 in transit (fig. 6). For a given car, the percent CO_2 at Chicago was about the same as the average percent CO_2 for the entire trip.

The O_2 level in a conventional car, at any given time during transit, was about equal to the difference between the CO_2 level in the car and the normal atmospheric O_2 level (21 percent). The lowest O_2 levels among the conventional cars occurred in cars 2 and 5 at destination when the O_2 was 15.5 and 15.0 percent, respectively. These O_2 levels were not low enough to affect the lettuce physiologically.

Transfresh cars.—The percentages of O_2, CO_2, and CO in the two Transfresh cars are shown in figures 7 and 8. The CO_2 averaged only 1.5 percent in both cars because the lime removed most of the CO_2 produced during respiration of the lettuce. The CO_2 levels at destination were 1.4 percent in car 1 and 2.3 percent in car 9. The CO, which averaged 1.0 or 1.5 percent in the cars at shipping point, averaged 1.0 and 1.3 percent during the trip, and 0.4 and 0.7 percent at destination in cars 1 and 9, respectively. These data are similar to those obtained in previous shipping tests with Transfresh cars in which the CO ranged from 0.4 to 0.6 percent at destination (see footnote 1, 1st par., p. 1).

During transit the O_2 level in Transfresh car 9 averaged 1.7 percent and in car 1, 3.9 percent. Apparently, car 9 was more tightly sealed than car 1 because the O_2 dropped considerably in car 9 between Chicago and destination. This drop was due to respiration of the lettuce. In car 1, however, the O_2 rose, probably because of leakage of air into the car. At destination, the O_2 was 0.4 percent in car 9 and 7.0 percent in car 1.

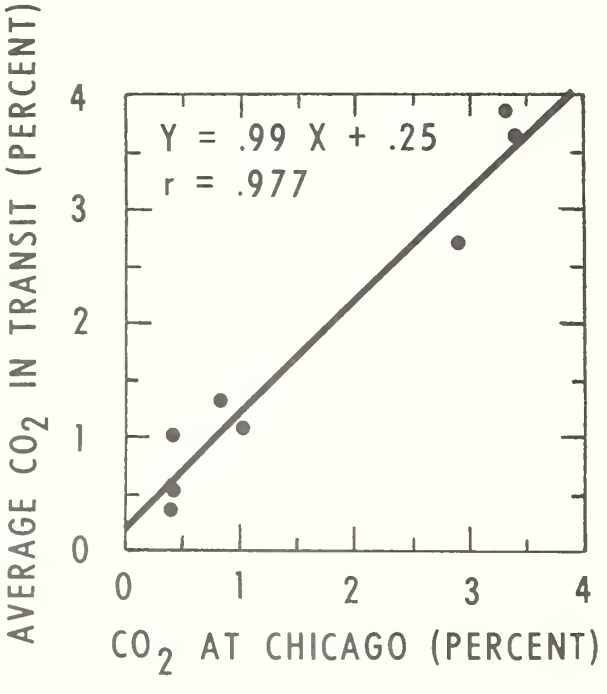

FIGURE 6.—Relationship between the carbon dioxide (CO_2) concentration in eight conventional cars of lettuce at Chicago, Ill., and the average CO_2 concentration in these cars during transcontinental shipment; r is significant at the 1-percent probability level.

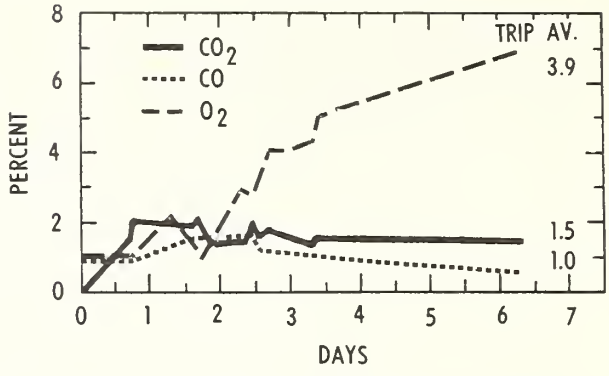

FIGURE 7.—Concentrations of carbon dioxide (CO_2), carbon monoxide (CO), and oxygen (O_2) in a Transfresh car of lettuce (car 1) shipped from Salinas, Calif., to New York, N.Y.

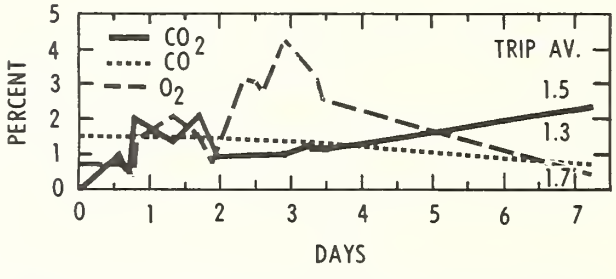

FIGURE 8.—Concentrations of carbon dioxide (CO_2), carbon monoxide (CO), and oxygen (O_2) in a Transfresh car of lettuce (car 9) shipped from Salinas, Calif., to Solon, Ohio.

Transit Temperatures

Transit temperatures of test packages in the top layers of the loads were in a satisfactory range, averaging 34° (car 6) to 38° F. (car 8) (table 2).

Market Quality

Brown stain.—A highly significant, positive correlation (r = 0.951) was found between the incidence of brown stain in the two cultivars at destination and the average percentage of CO_2 in the cars during transit—the higher the CO_2, the higher the incidence of brown stain (table 3). The two test lots of lettuce were not equally susceptible to CO_2 injury. Calmar had three times as many heads with brown stain ratings of slight or greater as did R-200. The difference in susceptibility of the two lettuce cultivars to brown stain may be due to a genetic difference or some other factor, but the cause could not be determined since the two cultivars were not grown in the same field. In addition, many of the Calmar heads were much firmer than the R-200 heads, indicating a difference in maturity at the time of harvest. The incidence of brown stain, however, was not influenced by the firmness of the heads in either cultivar (data not shown).

Significantly more brown stain was evident in lettuce at the second examination (after the 4-day period at 50° F.) than at the first examination (on arrival). This was also observed in previous laboratory tests. (See footnote 1, 2d par., p. 1). Although the injury occurs while the lettuce is held in the higher CO_2 levels, the brown stain lesions often do not become readily apparent until a later period in normal atmosphere and at increased temperatures.

The correlation between the CO_2 levels at destination and the incidence of brown stain (rated slight or greater) is shown in figure 9 for the cultivar Calmar at the second examination. The incidence of brown stain at this examination is comparable to what a housewife might encounter. The regression line indicates that lettuce from cars arriving with 1.0 percent CO_2 or less would probably have no brown stain, whereas, about 75 percent of the heads would be affected from cars arriving with 6.5 percent CO_2. From these data, apparently cars arriving with 2 percent CO_2 might have about 15 percent of the heads affected. Earlier shipping tests indicated that all cars or trailers arriving with 2 percent or higher CO_2 had some lettuce with brown stain. (See footnote 1, 1st par., p. 1.)

The incidence of brown stain in the two Transfresh cars was significantly higher than would be expected for cars averaging only 1.5 percent CO_2 (table 3 and fig. 9). This result was probably caused by the combination of increased CO_2 with low O_2 during transit. Previous laboratory tests showed that more heads developed brown stain when increased levels of CO_2 are combined with 3 percent O_2 than when combined with 21 percent O_2. (See footnote 1, 2d par., p. 1.)

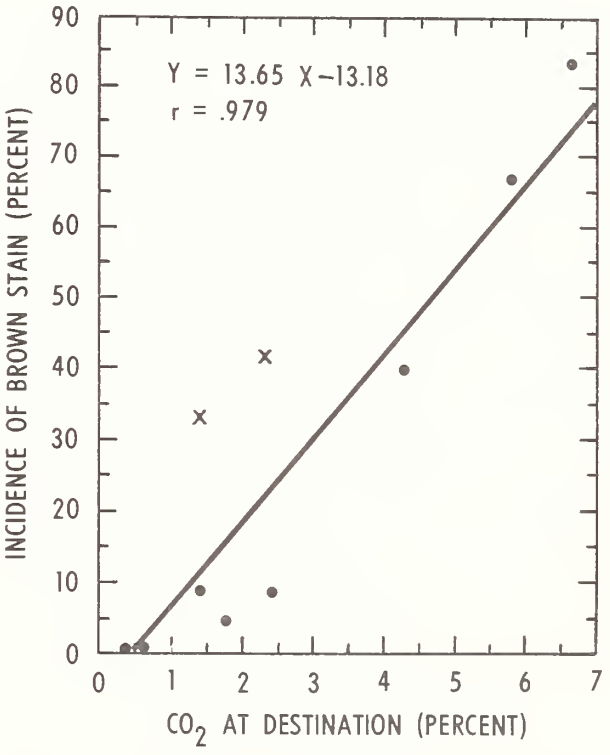

FIGURE 9.—Relationship between the carbon dioxide (CO_2) concentration at destination in eight conventional cars of lettuce and the incidence of brown stain (rated slight or greater) in cultivar Calmar (second examination):

r is significant at the 1-percent probability level.
x - incidence of brown stain in the two Transfresh cars.

TABLE 3.—*Incidence of indicated disorders and ratings for general external appearance and butt discoloration of lettuce shipped from Salinas, Calif., July 28, 1970*

Item	Average CO_2 conc. in transit	Incidence of indicated disorder [1]					Appearance of heads with wrapper leaves	Butt discoloration
		Brown stain	Russet spotting	Decay	Pink rib	Tipburn		
Test car No:	Percent	Percent	Percent	Percent	Percent	Percent	Rating [2]	Rating [3]
1 [4]	1.5	17.7	5.2	6.3	9.4	3.1	3.3	3.5
2	3.6	28.1	8.3	7.3	1.0	10.4	3.4	3.0
3	1.1	2.1	16.7	9.4	5.2	7.3	3.2	3.5
4	1.0	1.0	17.7	4.2	5.2	6.3	3.4	3.3
5	3.9	34.4	3.1	12.5	7.3	10.4	3.3	3.4
6	1.3	3.1	10.4	11.5	5.2	19.8	3.4	3.4
7	.5	0	15.6	9.4	6.3	12.5	3.2	3.5
8	.4	0	10.4	13.5	3.1	7.3	3.2	3.6
9 [4]	1.5	12.5	0	1.0	0	6.3	3.7	3.6
10	2.7	25.0	9.4	10.4	10.4	7.3	3.2	3.3
Variety:								
Calmar		18.5	3.3	14.2	4.6	2.9	3.1	3.7
R-200		6.3	16.0	2.9	6.0	15.2	3.5	2.8
Examination:								
Arrival		3.8	0	1.0	1.0	7.7	3.9	2.5
Arrival, plus 4 days at 50° F		21.0	19.4	16.0	9.6	10.4	3.8	4.1

Statistical Analysis (Mean Squares)

Source:	Degrees of freedom							
Cars	9	9.90**	1.97	0.87	0.63	1.22	0.09	0.37
Regression on CO_2	1	80.52**	2.23	− .79	.03	− .70	− .08	.03
Deviations, Transfresh	1	5.86**	11.65**	5.06*	2.60*	3.74	.67**	2.78**
Deviations, conventional	7	.45	.55	.51	.44	1.14	.05	.08
Variety (V)	1	21.76**	23.26**	18.22**	.31	21.76**	1.98**	7.74**
Error "b"	9	1.78	.92	.91	.38	1.20	.05	.13
Examination (E)	1	43.06**	54.06**	32.40**	10.51**	1.06	12.66**	23.41**
VXE	1	3.31	23.26**	16.90**	1.06	1.06	.65**	.32
Error "c"	18	4.06	1.45	.72	.39	.54	.05	.09

[1] Percentage of heads rated "slight" (3.0) or greater.

[2] Rating scale: 1, unsalable; 2, poor; 3, fair; 4, good; 5, excellent.

[3] Rating scale: 1, none; 2, trace; 3, slight; 4, moderate; 5, severe.

[4] Car atmospheres modified by Transfresh Corp.

* = Significant at 5-percent probability; ** = significant at 1-percent probability level.

Russet spotting.—Russet spotting was not influenced by the CO_2 level in transit, but it was influenced by the Transfresh atmosphere (table 3). Significantly fewer heads developed russet spotting in the Transfresh cars than in the conventional cars because of the low O_2 level in the Transfresh cars. Other tests have shown that low O_2 retards the development of russet spotting.[3]

Russet spotting developed in about one-fifth as many heads in Calmar as in R-200. However, the exact reasons for this difference are not known, because these cultivars were not grown in the same field and the maturity differed.

As in previous tests, russet spotting was significantly more prevalent after the lettuce had been held 4 days at 50° F. than at time of arrival. (See footnote 3, 2d par.)

Pink rib.—Pink rib was not significantly influenced by the CO_2 level in the cars. Lettuce from Transfresh car 1 had the second highest incidence (9.4 percent) of pink rib of all 10 cars, whereas lettuce from Transfresh car 9 had the least (0 percent). In previous shipping tests Transfresh atmospheres reduced pink rib (significant at the 5-percent probability level). (See footnote 1, 1st par.) The reason for the higher incidence of pink rib in Transfresh car 1 is unknown.

As in previous tests, pink rib increased significantly in all lots during the 4-day period at 50° F. (See footnote 1, 1st par., p. 1 and footnote 3, 2d par.)

Butt discoloration.—Butt discoloration in Transfresh car 9, examined at Solon, Ohio, was less (1.5 rating) at the first examination than that in any of the other cars (range 2.0 to 3.2 ratings). Butt discoloration rating at this time was 2.6 in Transfresh car 1, essentially the same as that in the conventional cars. At the second examination, however, butt discoloration in lettuce from Transfresh car 9 had increased to a rating of 3.6, almost the same as that for the conventional cars (range 4.0 to 4.2). Butt discoloration rating in car 1 was 4.2.

The small difference in oxygen concentrations in the two Transfresh cars (1.7 vs. 3.9 percent) is unlikely to account for the whiter butts in car 9 than in car 1 at the first examination. Rather, the difference is more likely due to the differential between unloading and the arrival examination of the two cars. Lettuce from car 9 was examined immediately after the car was unloaded, whereas about 12 hours elapsed after car 1 was unloaded before the test packages were evaluated. Transfresh atmospheres may retard butt discoloration during transit, but this difference apparently is largely lost within 12 hours after the lettuce is removed from the car.

Butt discoloration was significantly less severe in R-200 than in Calmar (table 3). This difference was especially noticeable at the first examination. Butt discoloration increased significantly in all lettuce during 4 days at 50° in air.

Decay.—Decay was not influenced significantly by the CO_2 level in the cars, but it was significantly different (at the 5-percent probability level) in the Transfresh cars (table 3). This difference was due primarily to the lettuce in Transfresh car 9 that had only 1.0 percent decay. All other test cars had greater amounts of decay.

Calmar had significantly more decay than R-200, possibly because Calmar was more mature than R-200 at harvest.

Decay increased significantly in all lots during 4 days at 50° F.

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[3] LIPTON, W. J. MARKET QUALITY AND RATE OF RESPIRATION OF HEAD LETTUCE HELD IN LOW-OXYGEN ATMOSPHERES. U.S. Dept. Agr. Mktg. Res. Rpt. 777, 9 pp., illus. 1967.

STEWART, J. K., HARVEY, J. M., CEPONIS, M. J., and WRIGHT, W. R. NITROGEN—ITS EFFECT ON TRANSIT TEMPERATURES AND MARKET QUALITY OF WESTERN LETTUCE SHIPPED IN PIGGYBACK TRAILERS. U.S. Dept. Agr. Mktg. Res. Rpt. 759, 14 pp., illus. 1966.

Tipburn.—Tipburn was not influenced by the CO_2 level, the Transfresh atmosphere, or examination time. However, R-200 had significantly more tipburn than Calmar.

General appearance—The general appearance of the heads (with wrapper leaves attached) was not influenced by the CO_2 level (table 3). However, the appearance of lettuce from Transfresh car 9 was rated significantly higher than that from the other cars and R-200 was rated higher in appearance than Calmar. As expected, all lots of lettuce were rated significantly lower in appearance at the second than at the first examination.

Weight Loss

Weight losses from test packages of lettuce during transit ranged from 0.5 (cars 3 and 4) to 1.1 percent (car 10) and averaged 0.7 percent (table 2). Transit weight losses of lettuce in Transfresh car 1 were not different from that of lettuce in conventional cars. Previous tests also indicate that weight losses during transit averaged about 0.5 percent, and that the weight loss was about the same for lettuce shipped in Transfresh-treated vehicles and vehicles with normal atmospheres. (See footnote 1, 1st par., p. 1.) No data are available on weight loss for lettuce from cars 8 and 9.

DISCUSSION

The lettuce tests demonstrated that the concentration of CO_2 that accumulates in recently constructed railcars of lettuce shipped to markets in the Midwest or on the east coast varies considerably and that a high percentage (about one-third) of such cars develop injurious levels of this gas. For a given lot of lettuce, the higher the average CO_2 concentration during transit, the higher the incidence of brown stain at destination.

Different lots of lettuce varied considerably in their susceptibility to CO_2 injury. Concentrations of CO_2 above 2 percent for 1 week in transit were injurious to the cultivar Calmar shipped from the Salinas, Calif., area, but less so to R-200. The reason for the difference in susceptibility to CO_2 injury could have been genetic or environmental. The two cultivars were not grown in the same field.

Transfresh atmospheres were supplied to only two cars and the results were not consistent in these two cars. Lettuce from one Transfresh car was evaluated immediately after the car doors were opened and the lettuce was unloaded, whereas that from the other Transfresh car was evaluated about 12 hours after the car was opened, although the lettuce was refrigerated during this delay. The two Transfresh cars were consistent, however, in the accumulation of CO_2 during transit (1.5 percent) and in that CO_2 in combination with low O_2 resulted in more brown stain of lettuce than in conventional cars.

A satisfactory method for preventing the accumulation of injurious levels of CO_2 during shipment of lettuce is needed. Possibly, cultivars of lettuce that are tolerant to high levels of CO_2 will be found, but short-term solutions may be in developing techniques to ventilate conventional cars by bringing in a limited amount of outside air. Another possibility is to use lime inside the car to absorb the CO_2.

The amount of lime used in the Transfresh cars in this test and in previous tests did not remove enough of the CO_2. Greater amounts or better methods of exposing the lime to the CO_2 in the car are needed to remove more of the gas. The efficiency of removing the gas might be improved by increasing the surface area of the lime exposed to the car's atmosphere or by placing the lime where more of the car's atmosphere will pass over and through it during normal air circulation.

APPENDIX

Rates of air leakage of the test cars were measured by the Pacific Fruit Express Co. after completion of the test. The PFE specifications for new cars indicate a maximum air leakage rate of 100 cubic feet per hour (cu. ft. per hr.) at 0.5-inch water pressure.

Rates of air leakage of the eight conventional test cars and the CO_2 concentrations in transit and at destination are shown in table 4. Leakage rates influenced the magnitude of the CO_2 buildup in these cars. Cars with leakage rates of 234 cu. ft. per hr. or higher did not build up excessively high concentrations of CO_2, whereas cars with leakage rates of 185 cu. ft. per hr. or lower did develop excessive CO_2 levels.

The negative correlation between the leakage rate of the cars and the percent CO_2 at destination was highly significant (fig. 10). Until these data were available, the reason or reasons for the variability in CO_2 levels in cars of lettuce at destination were unclear. These data, however, indicate that the principal reason for this variability is the wide range in leakage rates of the cars.

TABLE 4.—*Leakage rates and carbon dioxide (CO_2) concentrations in conventional test cars of lettuce shipped from Salinas, Calif., July 28, 1970*

Test car	Leakage rate [1]	CO_2 concentration in car	
		Average in transit	At destination
No.	Cu.ft./hr.	Percent	Percent
2	90	3.6	5.8
5	165	3.9	6.6
6	170	1.3	2.4
10	185	2.7	4.3
4	234	1.0	1.8
7	345	0.5	0.5
3	420	1.1	1.4
8	960	0.4	0.5

[1] The data are arranged in order of increasing leakage rate. The rates were determined by the PFE Co., using 0.5 inches water pressure.

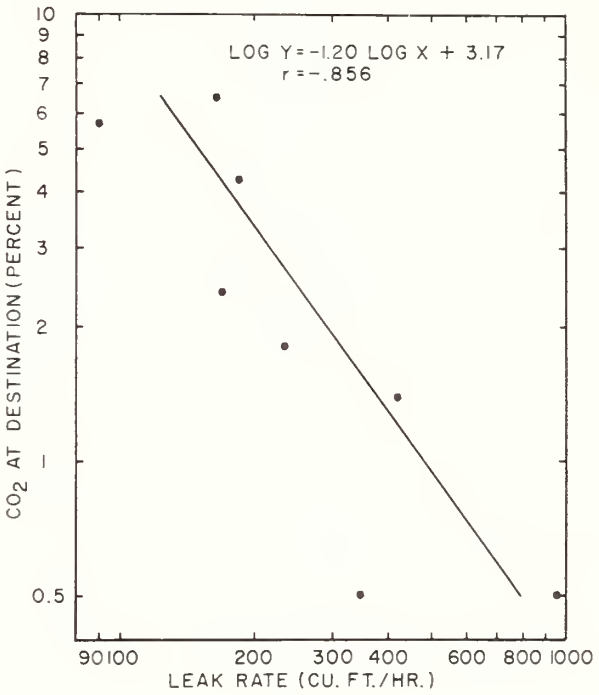

FIGURE 10.—Relationship between the leakage rate in eight conventional cars of lettuce and the carbon dioxide (CO_2) concentration in these cars at destination. (Figures for leakage rates and CO_2 concentrations were converted to logarithms for statistical analysis. The data are plotted on a log-log scale; r is significant at the 1-percent probability level.)

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